# Exertional heat illness incidence and on-site medical team preparedness in warm weather

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**Abstract:**

To investigate the influence of estimated wet bulb globe temperature (WBGT) and the International Institute of Race Medicine (IIRM) activity modification guidelines on the incidence of exertional heat stroke (EHS) and heat exhaustion (HEx) and the ability of an on-site medical team to treat those afflicted. Medical records of EHS and HEx patients over a 17-year period from the New Balance Falmouth Road Race were examined. Climatologic data from nearby weather stations were obtained to calculate WBGT with the Australian Bureau of Meteorology ($WBGT_A$) and Liljegren ($WBGT_L$) models. Incidence rate (IR) of EHS, HEx, and combined total of EHS and HEx (COM) were calculated, and linear regression analyses were performed to assess the relationship between IR and $WBGT_A$ or $WBGT_L$. One-way ANOVA was performed to compare differences in EHS, HEx, and COM incidence to four alert levels in the IIRM guidelines. Incidence of EHS, HEx, and COM was 2.12, 0.98, and 3.10 cases per 1000 finishers. $WBGT_A$ explained 48, 4, and 46% of the variance in EHS, HEx, and COM IR; $WBGT_L$ explained 63, 13, and 69% of the variance in EHS, HEx, and COM IR. Main effect of $WBGT_A$ and $WBGT_L$ on the alert levels were observed in EHS and COM IR ($p < 0.05$). The cumulative number of EHS patients treated did not exceed the number of cold water immersion tubs available to treat them. EHS IR increased as WBGT and IIRM alert level increased, indicating the need for appropriate risk mitigation strategies and on-site medical treatment.

**Keywords:** Wet bulb globe temperature | Activity modification | Road race medicine | Environmental stress

**Article:**

## Introduction

Exertional heat stroke (EHS), defined as an internal body temperature > 40 °C in conjunction with neuropsychological dysfunction, occurs when the body's thermoregulatory system is overwhelmed (Casa et al. 2015). Without prompt recognition and treatment of EHS, the risk of morbidity and mortality is increased (Adams et al. 2015). This excessive hyperthermia is multi-factorial in cause, with a combination of intrinsic and extrinsic factors being responsible for the onset of the condition (Casa et al. 2015). EHS is a risk for any individual performing intense exercise, especially when heat dissipation is impeded (i.e., exercising in hot and/or humid environmental conditions or wearing protective equipment in athletic, military, and occupational settings), with the highest incidence of EHS occurring in American football and warm-weather road running races (Grundstein et al. 2012; DeMartini et al. 2014).

High thermal loads from environmental conditions increase the risk of developing EHS by inhibiting heat loss from the body. When ambient temperature exceeds skin temperature, evaporation of sweat from the skin's surface becomes the primary means of body heat dissipation. However, when relative humidity of the environment is also elevated, the evaporative capacity of sweat diminishes, predisposing one to uncompensable heat gain (Kenny and Journeay 2010; Sawka et al. 2011; Casa et al. 2015). Prior literature examining the incidence of EHS and heat exhaustion (HEx) found that occurrences of EHS and HEx were greatest when environmental conditions became more extreme (Cooper et al. 2006; Grundstein et al. 2012; DeMartini et al. 2014). HEx is defined as an inability to continue exercise in the heat due to exercise-induced hyperthermia (< 40.5 °C), cardiovascular insufficiency, hypotension, energy depletion, and/or central fatigue (Casa et al. 2015). Although prognosis from HEx with body cooling, rehydration, and rest is benign compared to EHS, it may reduce one’s ability to withstand thermal strain since previous history of HEx has been associated with one of the risk factors of EHS (Casa et al. 2015).

Wet bulb globe temperature (WBGT) is an environmental index that factors in ambient temperature, relative humidity, and the radiant load from the sun. It has been used commonly in military and athletic settings to determine the environmental heat intensity experienced during exercise, and is calculated using the following equation (Yaglou and Minard 1957):

$$\text{WBGT} = (0.7 \times \text{Wet Bulb Temperature}) + (0.2 \times \text{Globe Temperature}) + (0.1 \times \text{Dry Bulb Temperature})$$

The American College of Sports Medicine (ACSM) (Armstrong et al. 2007), the National Athletic Trainers’ Association (Casa et al. 2015), and the International Institute for Race Medicine (IIRM) (Mears and Watson 2015) have established best practice recommendations using WBGT for activity modifications. These recommendations call for greater work-to-rest ratios or suspension of activities during extreme environmental conditions to mitigate the risk of both EHS and HEx. WBGT can be measured directly using a fixed station with three thermometers that measure wet bulb, shaded dry bulb, and black globe temperatures (Army 2013) or portable monitors (Cooper et al. 2017). However, due logistical and financial burden to implement these devices, numerous WBGT estimation formulas have been proposed by researchers that only require conventional weather data that can be acquired from a nearby weather station (Lemke and Kjellstrom 2012). For example, the formula developed by the Australian Bureau of Meteorology (ABM) only requires ambient temperature and relative humidity to compute WBGT, both of which are readily available in most locations (Lemke and Kjellstrom 2012). However, the ABM model was empirically derived and the amount of solar radiation and the wind speed may over- or under- estimate the actual condition. More complex formulas are also available that use multiple meteorological input to estimate WBGT; although the practical application may be more limited than the ABM model, the Liljegren model that estimates WBGT using ambient temperature, relative humidity, solar radiation, and wind speed has shown satisfactory congruence with the actual value (Lemke and Kjellstrom 2012).

Previous literature has also examined the influence of heat index, ambient temperature, and relative humidity on the occurrence of exertional heat illness (EHI) during summer road races (DeMartini et al. 2014); however, there is limited knowledge regarding the relationship of WBGT to the occurrence of EHS and HEx in the same scenarios. Additionally, no known literature has examined the relationship of EHS and HEx to current evidence-based environmental activity modification guidelines using WBGT during road races (Roberts 2010). Lastly, only empirical evidence is available in determining the number of cold water immersion (CWI) tubs required to prepare for warm-weather road races when a large number of EHS patients are expected, and no known literature has examined the number of CWI tubs needed per activity modification risk stratification. Therefore, the aims of this study were to (1) examine the relationship of estimated WBGT calculated by the ABM and Liljegren models on the incidence of EHS, HEx, and combined total of EHS and HEx (COM) during a summer road races, (2) investigate the differences in EHS, HEx, and COM incidence using WBGT-based activity modification guidelines, and (3) describe the readiness of an on-site medical team to treat EHS patients by comparing the number of best practice treatment modalities (i.e., CWI tubs) available versus the peak number of cumulative EHS patients treated over time. We hypothesize that a greater number of EHS, HEx, and COM incidents occur as environmental conditions get warmer and in a higher risk category within the WBGT guidelines.

## Methods

### Study design

This study was an observational study conducted at the New Balance Falmouth Road Race (FRR), which is an annual 11.3-km outdoor race that takes place in Falmouth, Massachusetts, USA, in late August. Climatological data were obtained on the day of the FRR over a 17-year period (1997, 1998, 2001, and 2003–2016) based upon the availability of medical tent records. Climatological data from 1999, 2000, and 2002 were not included in the analysis due to the lack of complete medical tent records from these years. Ambient air temperature and relative humidity were collected at the closest weather station to the race (Falmouth Village: N 41°32″57 ″, W 70°36′23″), which is located approximately at the 10.5-km marker along the race course. These data were then computed to the ABM model to calculate the estimated WBGT (Lemke and Kjellstrom 2012). Additionally, solar irradiance and wind speed data from the closest solar radiation station (Woods Hole: N 41°31″48 ″, W 70°39′35″), which is located approximately 2-km from the race start line, were obtained to compute estimated WBGT using the Liljegren model (Liljegren et al. 2008). Mean WBGT from the hours of 9:00 am to 11:00 am were used to represent the environmental conditions experienced by the participating runners for each year. Medical tent records of patients diagnosed with EHS or HEx were also obtained for the 17-year period from the FRR. Healthcare providers with the requisite skills (e.g., medical doctor, certified athletic trainer) diagnosed all EHS and HEx patients at the medical tent. The diagnostic criteria for EHS was a rectal temperature greater than 40 °C with concurrent neuropsychological dysfunction; other runners who were triaged to the medical tent for heat related issues without neuropsychological dysfunction were diagnosed as HEx.

## Study outcomes

Associations between the mean estimated WBGT using the ABM model ($WBGT_A$) or the Liljegren model ($WBGT_L$) and the incidence of EHS, HEx, and COM were investigated. Associations between EHS, HEx, and COM rates and environmental-based activity modification categories from IIRM (Table 1) in the morning prior to the start of the race (i.e., 8:00 am) were also investigated. Lastly, preparedness for EHS treatment by the on-site medical team was assessed for 3 years (2014, 2015, and 2016) by comparing the number of CWI tubs available versus the number of EHS patients admitted at a given time during the race. It was assumed that each patient required at least 30 min of cooling treatment and medical attention based on previously published literature describing common cooling rates for CWI (McDermott et al. 2009).

**Table 1.** The International Institute for Race Medicine race modification guideline

| Alert Level | Wet Bulb Globe Temperature | Event Conditions | Recommended Actions |
|---|---|---|---|
| Black (Extreme) | >28 °C | Event canceled<br>Extreme and dangerous conditions | Participation stopped<br>Follow event official instruction |
| Red (High) | 22–28 °C | Potentially dangerous conditions | Slow down<br>Observe course changes<br>Follow event official instruction<br>Consider stopping |
| Yellow (Moderate) | 18–22 °C | Less than ideal conditions | Slow down<br>Be prepared for worsening conditions |
| Green (Low) | 10–18 °C | Good conditions | Enjoy the event<br>Be alert |

Adapted from IIRM Medical Care Manual (Mears and Watson 2015)

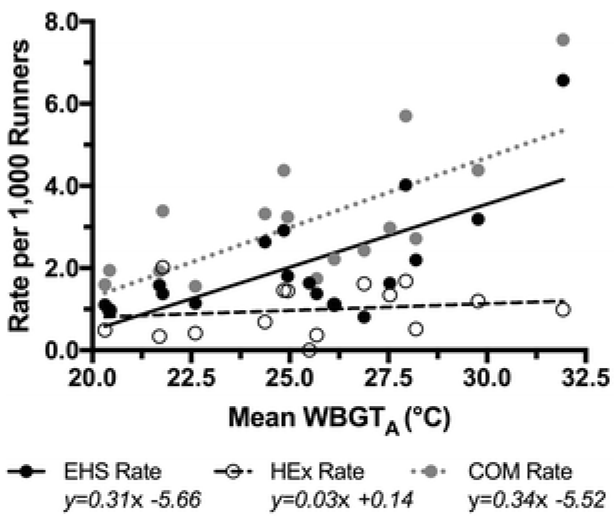
## Statistical analysis

All statistical analyses were performed using SPSS (version 21; IBM Corporation, Armonk, NY). Incidence of EHS, HEx, and COM per 1000 finishers was calculated for each year using the number of registered runners that completed the race. Linear regression analyses were used to calculate the association between mean estimated $WBGT_A$ and $WBGT_L$ and incidence rate of EHS, HEx, and COM. The differences between the IIRM race modification guideline categories and the incidence rate of EHS, HEx, and COM were analyzed using one-way analysis of variance (ANOVA) after the normality of data was confirmed using the Shapiro-Wilk test. Post-hoc analyses using the Bonferroni correction were conducted for comparisons that exhibited statistical significance, which was set a priori ($p < 0.05$).

# Results

## Associations with environmental data

Incidence of EHS, HEx, and COM was 2.12, 0.98, and 3.1 cases per 1000 finishers, respectively. Mean estimated $WBGT_A$ explained 48% of the variance observed in EHS ($R^2 = 0.48$, $p = 0.002$). Mean estimated $WBGT_A$ explained 4% of the variance observed in HEx ($R^2 = 0.04$, $p = 0.467$). Mean estimated $WBGT_A$ explained 46% of the variance observed in COM ($R^2 = 0.46$, $p = 0.003$). In comparison, mean estimated $WBGT_L$ explained 63% of the variance observed in EHS ($R^2 = 0.63$, $p < 0.001$). Mean estimated $WBGT_L$ explained 13% of the variance observed in HEx ($R^2 = 0.13$, $p = 0.196$). Mean estimated $WBGT_L$ explained 69% of the variance observed in COM ($R^2 = 0.69$, $p < 0.001$). These relationships between the above-mentioned variables are presented in Fig. 1.



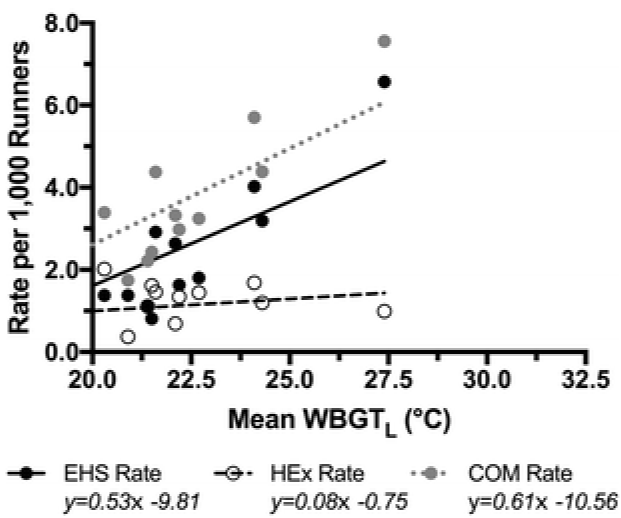




**Figure 1.** Top: relationship between the estimated mean wet bulb globe temperature using the Australian Bureau of Meteorology model ($WBGT_A$) and incidence rates of exertional heat stroke (EHS), heat exhaustion (HEx), and combined total of EHS and HEx (COM). Bottom: relationship between the estimated mean wet bulb globe temperature using the Liljegren model ($WBGT_L$) and incidence rates of EHS, HEx, and COM

Associations with race modification guidelines

The incidence rates of EHS, HEx, and COM based on the IIRM weather-based activity modification guidelines are depicted in Table 2. The Shapiro-Wilk test confirmed the normality of the data ($p > 0.05$) in all flag categories. Data from category Green (i.e., low alert level) in $WBGT_A$ and Black (i.e., highest alert level) in $WBGT_L$ were removed from the Shapiro-Wilk test and one-way ANOVA since the observations under these conditions were limited. There was a significant main effect of $WBGT_A$-based race modification guideline category on EHS ($p = 0.007$) and COM ($p = 0.020$) incidence rates when compared between the Black, Red, and Yellow categories. (Fig. 2a–c) Post-hoc comparison using the Bonferroni correction indicated that the mean EHS incident rate per 1000 finishers was greater in category Black vs. Red (mean difference (MD) [95% confidence interval]; 2.94 [0.69, 5.19], $p = 0.01$) and Black vs. Yellow (3.53 [0.85, 6.20], $p = 0.01$). Similarly, COM incident rate was greater in category Black vs. Red (3.07 [0.28, 5.86], $p = 0.03$) and Black vs. Yellow (3.67 [0.36, 6.98], $p = 0.03$). In comparison, there was a significant main effect of $WBGT_L$-based race modification guideline category on EHS ($p = 0.041$) and COM ($p = 0.029$) incidence rates when compared between the Red, Yellow, and Green categories (Fig. 2d–f). However, no significance in the Bonferroni post-hoc test was observed.

**Table 2.** Mean incidence rate of exertional heat illness per 1000 finishers by race modification guideline

| WBGT model | IIRM alert level | Exertional heat stroke | Heat exhaustion | Combined |
|---|---|---|---|---|
| ABM | Black | 4.89 ± 2.39 | 1.09 ± 0.15 | 5.97 ± 2.24 |
| | Red | 1.93 ± 0.95 | 0.97 ± 0.59 | 2.90 ± 1.26 |
| | Yellow | 1.35 ± 0.24 | 0.95 ± 0.93 | 2.30 ± 0.95 |
| | Green | 0.97 | 0.97 | 1.94 |
| Liljegren | Black | – | – | – |
| | Red | 3.31 ± 1.83 | 1.22 ± 0.35 | 4.53 ± 1.79 |
| | Yellow | 1.47 ± 0.68 | 1.05 ± 0.68 | 2.51 ± 1.01 |
| | Green | 1.04 ± 0.09 | 0.73 ± 0.34 | 1.77 ± 0.25 |

*WBGT* wet bulb globe temperature, *ABM* the Australian Bureau of Meteorology, *IIRM* the International Institute for Race Medicine

Estimated WBGT in the morning prior to the start of the race (i.e., 8:00 am) is used for the analysis. Incidence rates are reported in mean ± standard deviation

Assessment of race medical tent preparedness for exertional heat stroke treatment

The FRR finish line medical tent was equipped with 22 CWI tubs at the 2014 and 2015 races (2 CWI tubs per 1000 finishers), and 32 CWI tubs at the 2016 race (3 CWI tubs per 1000 finishers). Peak volumes of EHS patients were observed 45 min following the start of the race in 2014 ($n = 10$) and 2016 ($n = 13$), while it was observed 60 min following the start of the race in 2015 ($n = 19$). The peak cumulative number of EHS patients being treated at the finish line medical tent never exceeded the number of available CWI tubs in all 3 years (Fig. 3).

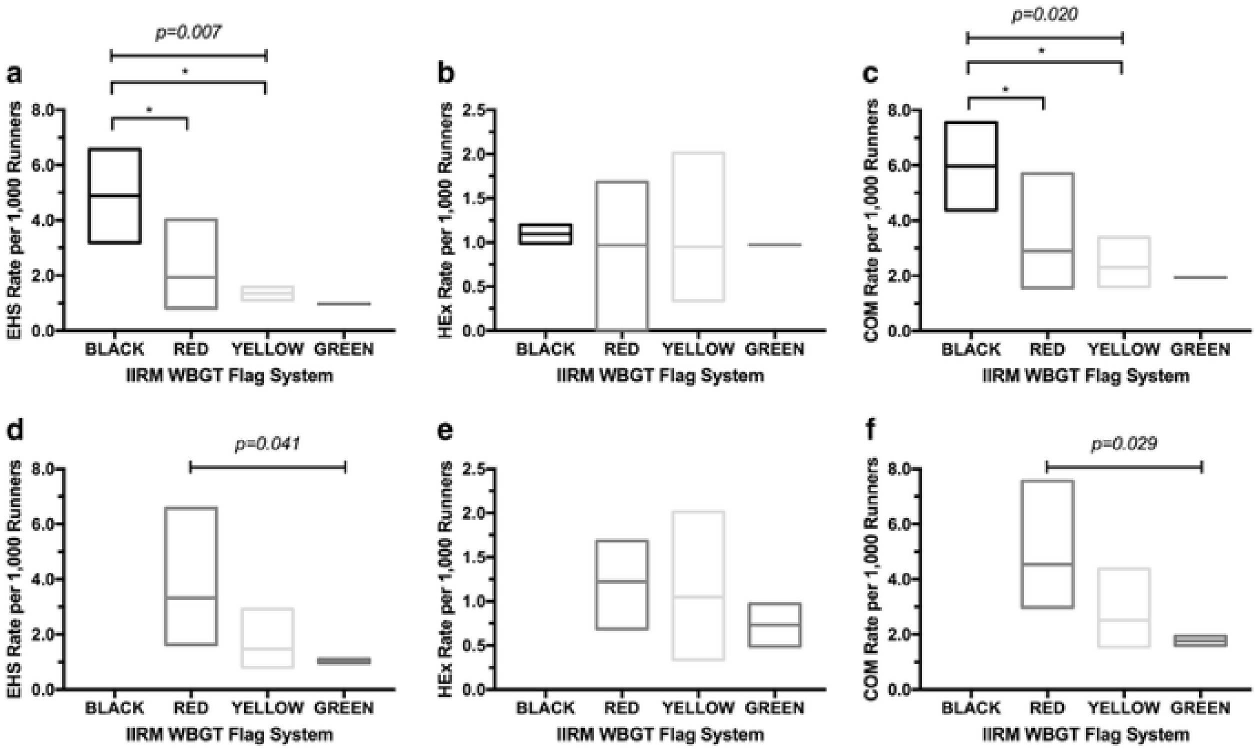



**Figure 2.** Relationship between the International Institute for Race Medicine race modification guideline category and incidence rates of exertional heat stroke (EHS), heat exhaustion (HEx), and combined total of EHS and HEx (COM) using wet bulb globe temperature estimates from the Australian Bureau of Meteorology model (**a**, **b**, **c**) and the Liljegren model (**d**, **e**, **f**). Upper and lower end of the box represents the maximum and minimum values, and the horizontal line represents the average value. The bracket with *p* values signify the main effect. Statistical significance was set at $p < 0.05$ a priori (*)

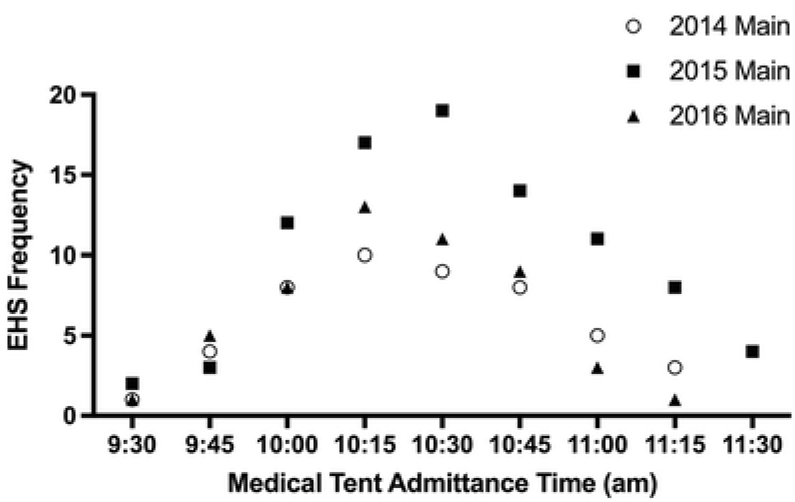



**Figure 3.** Admittance of exertional heat stroke (EHS) patients to the main medical tent and the number of cooling stations needed to effectively treat each patient assuming that each patient required at least 30 min of cooling treatment and medical attention. The race started at 9:00 am (zero point in the x axis)

## Discussion

The purpose of this study was to examine the relationship between estimated WBGT values derived from the ABM ($WBGT_A$) and Liljegren ($WBGT_L$) models and the incidence of EHS, HEx, and COM. Furthermore, we sought to compare the occurrences of EHS, HEx, and COM to current environmental activity modification guidelines and the preparedness of the medical team to provide onsite treatment of EHS. In line with our hypothesis, we found that as environmental conditions became more extreme, the incidence of EHS and COM was greater (Figs. 1 and 2). When compared between $WBGT_A$ vs. $WBGT_L$, $WBGT_A$ resulted in greater estimate values, which caused discrepancy in the IIRM categories (Fig. 2). Specifically, IIRM Black category (i.e., extreme conditions with recommended actions of stopping the event) was only observed when $WBGT_A$ was used.

Although the highest occurrence of EHS occurred when the environmental conditions were the most extreme in both WBGT models, the number of EHS cases never exceeded the capability to treat these patients on-site using standard of care practices. For example, the finish line medical tent at the FRR was equipped with 2–3 tubs per 1000 finishers, with each CWI tub staffed with at least one physician, one registered nurse, one athletic trainer, and one or more additional medical or non-medical volunteer staff. This demonstrates FRR's preparedness to treat EHS, providing seamless on-site treatment that resulted in zero fatalities. Therefore, we suggest that the availability of best practice EHS treatment resources (e.g., trained medical personnel, rectal thermometry, cold water immersion tubs, ice towels for the head and neck) (Casa et al. 2015) be factored into the decision-making process for summer road race medical directors who are faced with difficult decision making when warm weather is anticipated.

Previous research by DeMartini et al. investigated the influence of heat index, ambient temperature, and relative humidity on number of EHI observed at the FRR (DeMartini et al. 2014). Their findings demonstrated that the risk of EHI increases as environmental conditions increase; however, the study lacked external validity for clinical application since scientific and medical literature suggest the use of WBGT as best practice, not HI, to determine activity modifications (Armstrong et al. 2007; Mears and Watson 2015; Casa et al. 2015). HI is one of many indices that quantify thermal stress; nevertheless, the design of the HI was based on a shady, light-wind condition for a 170.2 cm (67 in), 66.7 kg (147 lb) man walking at 4.8 $km \cdot hr^{-1}$ (3$mi \cdot hr^{-1}$) while wearing long pants and a short sleeve shirt, which does not entirely represent the exercise context often observed among runners (Steadman 1979). Consequently, there are no activity modification guidelines for athletic activities that are based on HI. Instead, current study used the estimated WBGT values derived from two models: the ABM and the Liljegren (Liljegren et al. 2008; Lemke and Kjellstrom 2012). The model from ABM has its advantage of using a simple calculation, which only requires measures of ambient temperature and relative humidity for computation. However, Lemke and Kjellstrom (2012) have reported its limitation in outdoor WBGT estimation due to the lack of inputs regarding the solar irradiance and wind speed. On the contrary, the Liljegren model has shown to have good precision and accuracy in estimating the outdoor WBGT (Lemke and Kjellstrom 2012). However, the application of the Liljegren model in outdoor endurance races may be limited since solar irradiance and wind speed are not routinely measured by race directors and clinicians. The estimated WBGT values were always lower in the Lilgegren model ($-3.81$ [$-4.57$,

$-3.06]$, $p < 0.001$). This resulted the ABM and Liljegren models to only show agreement in the flag categories in 46.7% of the observations across EHS, HEx, and COM, with the Liljegren model exhibiting a lower flag category by one level in all the other cases where incongruities were observed (Fig. 2).

Elevated WBGT has also been shown to be associated with overall medical tent admittance during a marathon, which led Roberts (2010) to suggest that marathon events held at latitudes > 40°N should be canceled when the starting WBGT exceeds 21 °C due to the expected overflow of the on-site medical team's capacity. Falmouth, Massachusetts, is located at a latitude of 41°N; however, our data demonstrated that the race was well equipped to treat runners who are admitted to the medical tent. While we acknowledge that the risk of EHS was increased during years that experienced more extreme environmental conditions at the FRR, the medical team was well prepared to execute the acute care of those runners who sought medical attention for EHS as evidenced by the number of staffed CWI tubs and no deaths from EHS recorded in the history of the race (Demartini et al. 2015). The use of an injury surveillance system to optimize the medical tent preparedness in mass participation events has been investigated previously (Ross et al. 2015). Provided that each event would have its unique challenges (e.g., number of participants, climate, racecourse layout, and distance), it becomes critical that medical directors evaluate their preparedness from their own historical data to optimize their medical tent operations and needs (Mears and Watson 2015; Chiampas and Goyal 2015).

### Limitations

The estimated WBGTs used in this study were derived from the equation developed by the Australian Bureau of Meteorology (Lemke and Kjellstrom 2012) and Liljegren et al. (2008) using the values from two closest weather stations. These equations were used since our data acquisition was limited to the values collected at conventional weather stations. In recent years, the race has incorporated the use of on-site WBGT measurement with the globe temperature, which will allow for comparison between the weather station data and on-site measurement in the future. It should also be noted that runners on the race course may have experienced different microclimates compared to that of weather station due to the topographical differences. For example, although the race course at FRR only has a total ascent of 13.5 m (i.e., relatively homogeneous topography), it is comprised of areas with tree-shaded roads and open road by the beach, which may impact the direct heat gain from the solar radiation and also the pacing strategy which may influence the rate of heat gain through metabolic heat. Therefore, future research should also investigate the association of the incidence of EHS, HEx, and COM when compared to onsite measures of WBGT across varying points of the race course to account for microclimates that may be experienced by runners during the race. In conjunction, future research investigating the relationship between the heat gain of runners compared to exercise intensity in addition to any microclimate differences along the race course may provide a better understanding of the interaction between environmental conditions, exercise intensity, and risk of EHS.

## Conclusions

In light of the present investigation being conducted at a summer road race, an increased incidence of EHS and COM is linked to warmer environmental conditions. Findings from the linear regression analyses suggest that the Liljegren model explained more variance in EHS, HEx, and COM than ABM model. Furthermore, the IIRM WBGT activity modification guidelines adequately stratify the incidence of EHS and COM on the basis of environmental conditions. Additionally, flag categories derived from the Liljegren model exhibited agreement with the medical tent observations in that cancelation of the event was not necessitated given the proper provisions implemented at the Falmouth Road Race. In the three years studied, despite a relatively high incidence of EHS, the cumulative patient load never exceeded the number of available best practice treatment modalities (CWI tubs). Therefore, race directors and medical directors should consider adjusting the number of staffed CWI tubs and the race modification accordingly to the observed environmental conditions.

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